PROCEDURE FOR ACHIEVING IMPROVED BEARING CAPACITY OF 2ND LAYER SUBSOIL FOR DEVELOPMENT OF BI-LAYER FOUNDATION SYSTEM

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ABSTRACT

This paper deals in detail about how to achieve more improved safe bearing capacity of weak subsoil pertaining to surface soil of a new foundation system known as Bi-Layer Foundation System. This system implies towards the development of surface foundation for multistorey buildings and road foundation. Bi-layer foundation has two level hard layers across the vertical axis of a single column or a group of columns in combination. Hence it demands two kinds of safe bearing capacity of subsoil layers – one is untreated site occurrence and other is treated engineered base. Out of these two layers, the 2nd level layer is engineered at shallowest depth or surface level with desired higher bearing capacity. For feasibility of such design conception in consistence to the theory of bi-layer foundation, targeted higher bearing capacity so needed is to be achieved through hard inclusion as treated layer. Present study is presented for how to achieve the improved bearing capacity in the laboratory Model tests besides some other aspects. Three series of model PLT were carried out by using 3 different types of soil in the Laboratory. In these series, two varieties of preparations of soil layers were maintained. First variety was done for untreated ground i.e. the subsoil available at site condition which is forming the 1st layer below propounded surface foundation. And the 2nd variety was carried out as combined efforts to improve the naturally occurred weak subsoil treated with open cell type hard inclusions, the inner space of which is filled with granular soil mass targeting towards materializing the new conception of this system. In conclusion, it is found that – recommendation of improved SBC particularly for 2nd layer of foundation subsoil comprising this conception, treated with hard inclusions can possibly be made out through the laboratory model PLT only, which reveals about 3 times more value of bearing capacity than that of its untreated one.

KEYWORDS: Subsoil, Foundation, Treated, Inclusion, Improved Bearing Capacity, Characteristic Ratio

INTRODUCTION

Introduction in General

Foundation design practices have undergone vast improvement from principally empirical base to knowledge base. The modern geotechnical engineers have improved their understanding of soil behaviour and sharpened their analytical tools and developed the suitable technology accordingly. However, full advantage of these developments has not been taken to improve design practices not only in India but also in almost all developing countries of our present globe. Of course, there are a few who want to achieve better engineered quality of their substructures only from economic gaining point as well as safety aspects. The negative habits exist because, the existing gap between a geotechnical engineer and a designer of Structures together with the Architecture's rigidity. Similarly, on the other hand even the attitude of most of the expert designers who use to assume in most cases the basic inputs (real data) pertaining to the relevant properties of subsoil supporting the foundation which in fact, underscoring such newer and scientifically more economic and reliable modern development. This is a matter of real understanding, the lack of which becomes the basic reason of failure of substructures

more particularly in multistorey rcc building in weak subsoil. Hence, the improvement of weak subsoil is not only essential but it shall be a mandatory requirement for low to medium rise multistorey buildings.

Therefore, this paper deals in details about how to achieve more improved safe bearing capacity (SBC) of weak subsoil pertaining to surface soil forming the structural layer of a new foundation system which is known as Bi-Layer Footing Foundation System (BL-FFS). This BL-FFS implies towards the development of surface foundation for multistorey buildings (Bayan, 2011.a & b) and road foundation (Bayan, 2012.a&b). Thus the introduction of such new foundation system for multistorey rcc building of low to medium height (say from 3-storey upto 12 storeys height) to be placed on weak subsoil (SBC <150 kN/m^2) of high earthquake prone area (i.e. area having Basic horizontal seismic coefficient =0.08) is found after Bayan (2011.a &b).

Bi-Layer Footing Foundation System

General Concept of Bi-Layer Foundation System

The simplest definition of this conception as per Bayan (Bayan, 2013.a) is: The foundation system (road/building) comprising two structural soil foundation level with hard layer at different depth for a load system (single/group), which possesses more efficient rate of transmission power of high structural load from shallowest to shallow depth into the subsoil in-terms-of more safety and economic aspect of engineering development, is called Bi-layer foundation system (BL-FS). This BL-FS has two horizontal hard material levels across the vertical axis of the single or group loading system. It implies to hold two different kinds of subsoil below the loading base to transmit the factored load by using two different SBC. Obviously, the surface foundation soil mass demands high range of elasticity and SBC to produce desired interaction (Bayan, 2013.b).

Definition and Working Process of Bi-Layer Footing Foundation

Bi-Layer Footing Foundation (BL-FF) is completely a new concept of multi-storey building foundation construction. It comprises the construction of surface and shallow foundation at a same location, not only in India but also in most of the urban cities of our present globe. Hence, it is a fresh subject. There are rarely found published knowledge besides Bayan (2013.a; 2011.a&b) which proclaims constructed structures in BL-FFS in possession. BL-FFS is useful from the economic aspect as well as from the simplest engineered construction habit point of view for low to medium rise of multi-storey buildings. It is also propounded that this BL-FFS can replace the deep foundation needed by conventional practice to some extent and may save more than 60% budget money kept for development of substructure of a proposed building project (Bayan, 2013.a and 2011.a).

The simplest definition is: The foundation system which possesses more efficient rate of transmission power of building load into a shallowest to shallow depth located weak layers of structural subsoil through two different structural foundation slab, in-terms-of more safety and economic aspect of engineering construction, is called Bi-layer footing foundation system. This BL-FFS has two footing slab across the vertical axis of a single column or a group of columns in combination. That means it has two footing slabs at two different levels of subsoil below a single column base to transmit the building load by using two layers of different soil mass. Consequently, the two footing slabs need two values of SBC to produce total mode of soil-structure interaction.

In consistence to the above idea, 1st level of footing slab placed at a suitable greater shallow depth below column base, which is made always as per conventional design practice of Isolated Footing Foundation (IFF) is to bear a smaller part of the total building load i.e. 1/3 of total loads as per the conception of BL-FFS. However, the bigger part of the total building load i.e. the remaining 2/3 of the total factored load and moment of a column or whole building, is normally

allowed to bear by 2nd level footing slab placed at shallowest or surface level i.e. just below Normal Ground level or occasionally at elevated level (Bayan, 2013.a) which may be at Plinth level of the Building for economic point of view, below column base. Hence this 2nd level foundation system is also termed as Surface Footing Foundation (SFF). In this regard, the detail design procedure of which is found after Bayan ((Bayan, 2013.a;2011.a&b). Obviously, such SFF is to be designed based on the engineered SBC i.e. improved SBC only. Therefore, present study will proclaims about how to achieve the targeted improved SBC for designing the BL-FFS. In this regard, Figure 1(a&b) demonstrating the location of 2nd layer of foundation subsoil within BL-FFS to be engineered for achieving high SBC at site.
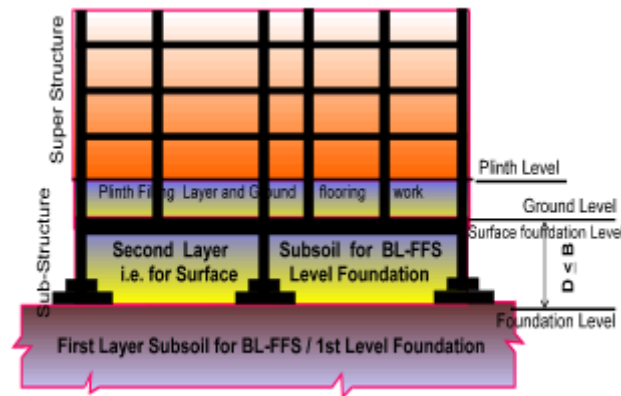

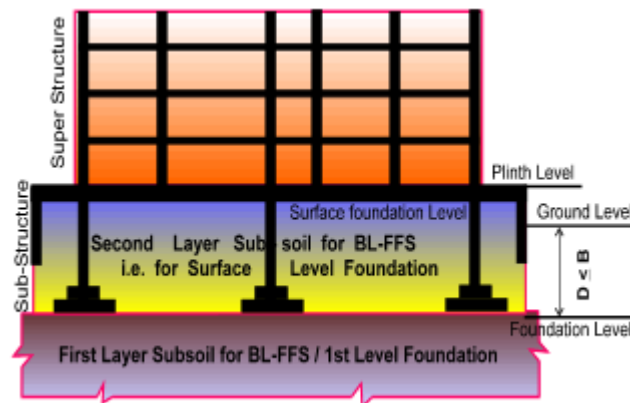**Figure 1(a) : Normal Pattern BL-FFS (Idealised 60% Economic)**

Figure 1(b): Elevated Pattern BL-FFS (Idealised >60% Economic)

Figure 1: Illustrations Demonstrating the Location of 2nd Layer of Foundation Subsoil within the BL-FFS

EVALUATION OF IMPROVED SBC FOR BI-LAYER FOOTING FOUNDATION SYSTEM

Need of Improved SBC

For development of surface foundation under BL-FFS, higher range of design SBC, which is more than the site occurrence, is needed. Such design SBC is normally not available on surface level or in the shallowest depth. To achieve such desired SBC engineered subsoil layer possessing better geotechnical properties is to be built up scientifically. Thus the present study is made how to achieve such layer of engineered soil mass yielding desired SBC, the procedure of which is described in succeeding subsections.

Procedure and Experimental Evaluation

Three series of model Plate Load Test (PLT) were carried out by using 3 different types of soil in the Laboratory. In these series, two varieties of preparations of soil layers were maintained. First (1st) variety was done for untreated

ground i.e. the subsoil available at site condition which is forming the 1st layer below propounded surface foundation (Figure 1) And the 2nd variety was carried out as combined efforts to improve the naturally occurred weak subsoil treated with open cell type hard inclusions, the inner space of which is filled with granular soil mass targeting towards materializing the new conception of BL-FFS.

It is already stated that - three different kinds of soil were considered to conduct 3 series of model PLT. Each series has 12 numbers of tests defined by different field conditions generated by some hard inclusions. It was kept in mind that the field condition applied shall be representative and the observed behaviors shall be materialized. To carry out the series of tests, geotechnical properties of the 3 kinds of subsoil used in this study were evaluated and are given in Table-1.

Table 1: Geotechnical Properties of the Subsoil of Laterite Origin Used to Carry out the Model PLT

Sl. no.	Type of soil used	Location of undisturbed soil Samples	Depth of sample 'D' in metre	Field Bulk density 'γ' in gm/cc	Natural moisture content 'W' in %	Sieve analysis (p. c. passing) size in mm									Shear parameters at Wet density1.85 & moisture content 16.5%	
						40 mm	20 mm	10.0 (IS: 10)	4.75 (IS: 480)	2.36 (IS: 240)	1.18 (IS: 120)	0.60 (IS: 600 micron)	0.3 (IS: 300 micron)	0.075 (IS:8 =75 micron)	Cohesion 'c' in kg/cm²	Angle of internal friction 'φ' in degree
1.	Type-I:: Pale yellowish Brown colour Laterite soil of Lake deposit in recent origin;	Mixed Sample from site	1.2	1.85	9.2	100	90.2	84.2	90.9	75.2	69.3	53.9	40.1	25.89	0.10	29.75
						F.M = 3.64										
2.		UD Sample from site	2.0	1.95	7.4	100	100	90.1	87.3	81.4	75.2	62.2	47.3	18.5	0.25	35.0
						F.M = 2.38										
3.	Type-II:: Reddish Brown Colour in wet condition Laterite soil of Lake deposit in recent origin;	Mixed Sample from site	1.2	1.90	13.3	100	95.3	93.6	87.3	79.9	73.2	60.9	50.7	21.8	0.06	33.2
						F.M = 2.97										
4.		UD Sample from site	2.0	1.92	12.5	100	100	90.1	87.3	80.4	75.2	62.1	47.5	18.5	0.05	34.3
						F.M = 2.88										
5.	Type-III:: Light Blackish Gray Colour in wet condition Colluvial soil of Local Lake deposit in Tertiary period of geological origin;	Mixed Sample from site (K-1)	1.0	1.93	10.9	100	100	93.2	80.8	81.1	55.9	61.8	43.4	18.32	0.03	34.9
						F.M = 4.62										
6.		UD Sample from site (K-2)	1.5	1.94	7.6	100	96.2	80.2	74.7	66.2	59.6	46.7	34.7	15.5	0.05	37.6
						F.M = 4.01										
7		UD Sample from site (K-3)	2.0	1.96	15.4	100	99.3	92.1	88.4	83.5	78.0	68.0	58.0	39.0	0.09	33.8
						FM = 5.54										

In the laboratory, Model PLT were carried out under *Treated and Under treated phases.* In the case of treated phases, a layer of granular soil mass is created with some engineering processes and placed just below loading plate which is acting as foundation level to conduct and to complete the tests. The testing situation in laboratory condition is shown in Figure 2. Thus, Figure 2 illustrating all about whole arrangement of numerical model PLT carried out in the laboratory.
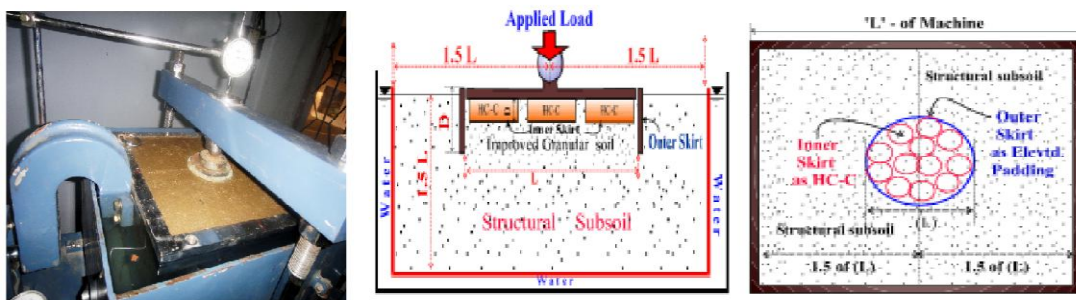

Figure 2(a): Photograph of PLT Figure 2(b): Schematic Drawing of PLT in Sectional Elevation
Figure 2: (c) Schematic Drawing of PLT in PLAN

Figure 2: Shows the Conduction of Model-PLT in the Testing Machine with Schematic Diagram

This granular layer is named after their process of treatment engaged to generate improved field condition and generating better geotechnical properties. The process involved consisting of development of inner confining ring as open cell type mass particle and outer skirt. Accordingly, filling materials may also vary in two ways e.g. same type of structural subsoil available in site to be used as 1st layer and improved quality granular soil (IQGrS) for 2nd layer and underneath is site original massive subsoil (Figure 2).

Both inner skirt, which is known as micro *cell particle* to the system and outer skirt, which is known as *skirt padding* are defined by their characteristics ratio (CR). In this regard for all model PLT, the depth (D) implies to the total used length of the ring type structural inclusion and the length (L) implies to the outer diameter of the ring type inclusion. The ratio of depth (D) to length (L) is termed as CR. Such confined soil cell particle is arranged as honey comb cell (HC-C) manner (Figure 2.c) placed in a same plane treated with confined pressure of outer skirt which is placed as elevated skirt padding or untreated with outer skirt condition. In this regards, Table 2 gives some characteristics account of such hard inclusions used in conducting the series of tests as model PLT.

Table 2: Characteristics Properties of Hard Inclusions Used in the Series of Tests

Particulars of items and their materials used to conduct the tests	Dimensions in (mm)			Characteristics Ratio (CR) = Depth to Length	Area within skirts used as individual/group in (mm^2)
	Outside Diameter (L)	Inside Diameter	Depth (D)		For PLT
					As individual/ group inclusion without soil
1. Outer Skirt of Steel (Sk-1)	115	107	32	0.278	Area of 1 Sk 10386.9
2. Outer Skirt of Steel (Sk-2)	60	54	23	0.383	Area of 1 Sk = 2827.4
3. Inner skirt (HC-C) as cell of PVC					
3(a) PVC-1	40	36	5	0.125	Area of 4 Sk 5026.5
3(b) PVC-2	25	22	5	0.200	Area of 4 Sk 1963.5
3(c) PVC-3	23.5	21	11	0.468	Area of 4 Sk 1828.4
3(d) PVC-4	23.5	21	20	0.851	Area of 4 Sk 1828.4
3(e) PVC-3	23.5	21	32	1.36	Area of 4 Sk 1828.4
4. Inner skirt HC-C of Steel (STL)	19	17	19	1.000	Area of 7 Sk 1984.7
5. HC-C of Steel	19	17	32	1.68	Area of 7 Sk 1984.7

Similarly, the IQGrS when treated with outer skirt is generating another characteristic ratio which is termed as improved granular soil ratio (IGSR). This ratio is also found out as L/D of the Skirt. However, the D is defined as – total thickness of compacted granular mass inside the skirt.

In reality, the combination of this CR and IGSR as a thin engineered layer to this foundation system governing the surface foundation for Road (Bayan, 2012.b) and low rise buildings upto 12 storey height (Bayan, 2013.a&b; 2012.a&b; 2011.a&b). However, such treatment is extensively differing by principle and application as and when the subsoil ground is treated with granular piles/ stone columns (Bayan, 2003).

Evaluation of Improved SBC

About 36 number of different model tests were conducted under various field conditions to evaluate the improved SBC over untreated subsoil with the 3 kinds of subsoil considered as given in Table 1and carriedout on different diameters and lengths of HC-C hard inclusions. In such studies, the overall settlement behaviours and increase in bearing capacity were observed in the Large Box Direct Shear Machines (Figure 2.a). For comprehensive understanding, a series of 12 tests carried out by using soil Type-I and the laboratory notes of such 3 consecutive MPLT were tabulated and are given in Table 3 and Table 4 respectively.

Similarly, graphical representation of all form of tests were also plotted in Log-Log and linear scale graph papers. By using these two kinds of graphs evaluation of ultimate load in Tonnes, Yield stress in (t/m^2), Factor of Safety (FoS) and net safe bearing capacity (SBC) in (t/m^2) were find out, a few of which are given in Figure 3 (a&b) and Figure 4 (a&b) revealing such engineering values in graphical solution.

Table 3: Details of Various Kinds of Model PLT Carriedout with SUBSOIL of Type-I

Model Test No. & Date of testing	Skirting condition		Honeycomb-cell condition		Results observed			% of improvent of SBC over field
	d & IGSR	Test Plate	Ring no. & CR	Thickness	Ulti-L/Y-Str	FoS	FoS/SBC	
Model Test No.-1 8/7/2011	No	7x7.1 cm2 Conc.	Nil	Nil	600 205	2.927	3.5 171.4	Field value 107
Model Test No.-2 11/7/2011	No	9.86 cm dia steel	Nil	Nil	375 117	3.205	3.5 107.1	Field value 107
Model Test No.-3 22/7/2011	d= 5.98 cm 0.334	5.98x5.98 stell plate	Nil	2 cm Sand alone	470 230	2.043	2.1 223.8	108.4
Model Test No.-4 26/7/2011	d= 9.9 cm 0.202	9.86 cm dia steel	Nil	2 cm Sand alone	360 150	2.400	2.5 144.0	34.6
Model Test No.-5* 27/7/2011	d= 10.64 cm 0.188	9.86 cm stell plate	12 nos.pvc 0.85106383	2 cm Sand 2 cm ht ring	500 285	1.754	1.8 277.8	159.8
Model Test No.-6 29/7/2011	d= 10.64 cm 0.188	9.86 cm stell plate	14 nos.pvc 0.468085106	2 cm Sand 1.1 ht ring	365 165	2.212	2.3 158.7	47.7
Model Test No.-7 1/8/2011	d= 10.64 cm 0.188	9.86 cm stell plate	12 nos.pvc 1.361702128	2 cm Sand 3.2cm ht ring	365 138	2.645	2.7 137.7	28.0
Model Test No.-8 3/8/2011	d= 10.64 cm 0.301	9.86 cm stell plate	12 nos.pvc 1.361702128	3.2cm Sand 3.2cm ht ring	480 122	3.934	4.0 121.5	13.1
Model Test No.-9 5/8/2011	d= 10.64 cm 0.301	9.86 cm stell plate	No ring sand only	3.2cm Sand alone	495 138	3.587	3.6 137.5	28.0
Model Test No.-10 9/8/2011	d= 10.64 cm 0.301	9.86 cm stell plate	20nos.Steel 1.739130435	3.2cm Sand alone	380 158	2.405	2.4 158.3	47.7
Model Test No.-11 11/8/2011	Nil	9.86 cm stell plate	20nos.Steel 1.739130435	driven to field soil	570 140	4.071	4.1 139.0	29.9
Model Test No.-12 13/8/2011	Nil	9.86 cm stell plate	12nos. Pvc 1.361702128	driven to field soil	470 147	3.197	3.2 146.9	37.4
* Optimum Skirting and H-CC condition revealing the best suited results of SBC & settlement								

Table 4: Details on Laboratory Notes for Conduction of 3-Kinds of Model PLT Carriedout with Subsoil Type-I

Model- Test No. 4   (Date of test: 26-07-2011)
(4) Restrained (i.e. Engineered) test for Top i.e. 2nd Layer Foundation soil:
Model PLT test was performed in the LB-DST machine with Water table below Footing. Type-I site Subsoil was taken as Field soil available as it is (Ref: Sieve analysis which is a mixture of all particles), as the Base ground of the test: Its remoulding properties are:
 (a) Wet density after moulding= 1.88 gm/cc
 (b) Moisture at moulding=14.95%
Tested layer made of same soil after passing 10mm sieve;
The properties of the Compacted ground of the test layer within skirted Pad of 2 cm height are:
 (a) Wet density after moulding= 2.0 gm/cc
 (b) Moisture at moulding=14.95%
Size of test Plate= Steel Plate of 9.86 cm dia
 Area of Test Plate = 76.35 sq.cm
Size of Skirting Pad = Steel Ring of
 (a) Outside dia = 11.60 cm
 (b) Inside dia = 9.95 cm
 (c) Internal area = 77.76 sq cm

Load in Kg/cm2	Total settlement (mm)		Unrestain SBC
System wt	Observed	Corrected	in Kn/m2
0.822	0.33	0.00	Total
1.244	0.74	0.41	BC=29
1.455	0.95	0.62	t/Sq.m
1.913	1.45	1.12	
2.512	2.14	1.81	
3.111	3.36	3.03	
3.710	12.33	12.00	*
* Contineous failuring stage occurred			

Model- Test No. 5   (Date of test: 27-07-2011)
(5) Restrained (i.e. Engineered) test for Top i.e. 2nd Layer Foundation soil:
Model PLT test was performed in the LB-DST machine with Water table below Footing. Type-I site Subsoil was taken as Field soil available as it is (Ref: Sieve analysis which is a mixture of all particles), as the Base ground of the test: Its remoulding properties are:
 (a) Wet density after moulding= 1.90gm/cc
 (b) Moisture at moulding=11.24%
Tested layer made of same soil after passing 10mm sieve;
The properties of the Compacted ground of the test layer within skirted Pad of 2 cm height are:
 (a) Wet density after moulding= 2.0 gm/cc
 (b) Moisture at moulding=11.24%
Size of test Plate= Steel Plate of 9.86 cm dia
 Area of Test Plate = 76.35 sq.cm
Size of Skirting Pad = Steel Ring of
 (a) Outside dia = 11.47 cm
 (b) Inside dia = 10.64 cm
 (c) Internal area = 88.578 sq.cm
Size hard Inclusion rings: (Total number of testing ring PVC taken = 12 nos, of total volume = 20 cc)
 (a) Outside dia = 2.35 cm   (b) Inside dia = 2.10 cm
 (c) Height = 2.00 cm   (d) Internal area =   3.463614 sq cm
 (e) Internal volume per ring =   6.9272 Cu. cm
The rings were filled with Compacted soil of the same nature.

Load in Kg/cm2	Total settlement (mm)		Unrestain SBC
System wt	Observed	Corrected	
0.822	0.39	0	Total
1.244	0.70	0.31	BC=36
1.455	0.88	0.49	t/Sq.m
1.913	1.22	0.83	
2.512	1.61	1.22	
3.111	2.08	1.69	
3.710	2.75	2.36	
5.083	9.23	8.84	*
* Contineous failuring stage occurred			

Model- Test No. 6   (Date of test: 29-07-2011)
(6) Restrained (i.e. Engineered) test for Top i.e. 2nd Layer Foundation soil:
Model PLT test was performed in the LB-DST machine with Water table below Footing. Type-I site Subsoil was taken as Field soil available as it is (Ref: Sieve analysis which is a mixture of all particles), as the Base ground of the test: Its remoulding properties are:
 (a) Wet density after moulding= 1.93 gm/cc
 (b) Moisture at moulding=11.75%
Tested layer made of same soil after passing 10mm sieve;
The properties of the Compacted ground of the test layer within skirted Pad of 2 cm height are:
 (a) Wet density after moulding= 2.0 gm/cc
 (b) Moisture at moulding=11.75%
Size of test Plate= Steel Plate of 9.86 cm dia
 Area of Test Plate = 76.35 sq.cm
Size of Skirting Pad = Steel Ring of
 (a) Outside dia = 11.47 cm
 (b) Inside dia = 10.64 cm
 (c) Internal area = 88.578 sq cm
Size hard Inclusion rings: (Total number of testing ring PVC taken = 14 nos, of total volume = 12.5 cc)
 (a) Outside dia = 2.35 cm   (b) Inside dia = 2.10 cm
 (c) Height = 1.10 cm   (d) Internal area =   3.463614 sq cm
 (e) Internal volume per ring =   3.80996 Cu. cm
The rings were filled with Compacted soil of the same nature.

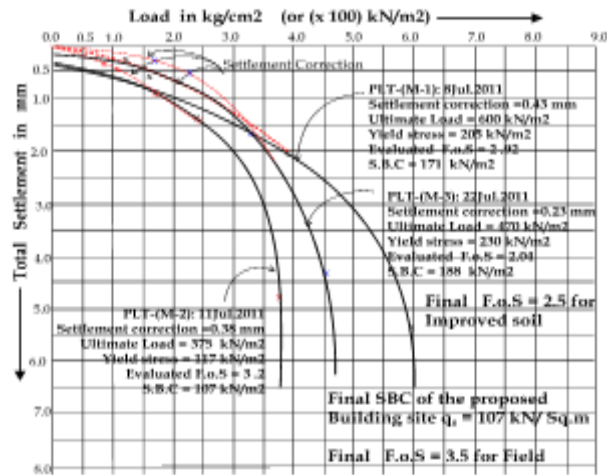| Load in Kg/cm2	Total settlement (mm)		Unrestain SBC
System wt	Observed	Corrected	
0.822	0.47	0	Total
1.244	0.76	0.29	BC=36.5
1.455	0.98	0.51	t/Sq.m
1.913	1.45	0.98	
2.512	2.05	1.58	
3.111	2.93	2.46	
3.710	9.21	8.74	*
* Contineous failuring stage occurred			

Figure 3(a): Load Settlement Curves Revealed from PLT Model Tests No 1,2 & 3 on Untreated Subsoil of Type-I Soil Given in Table-1

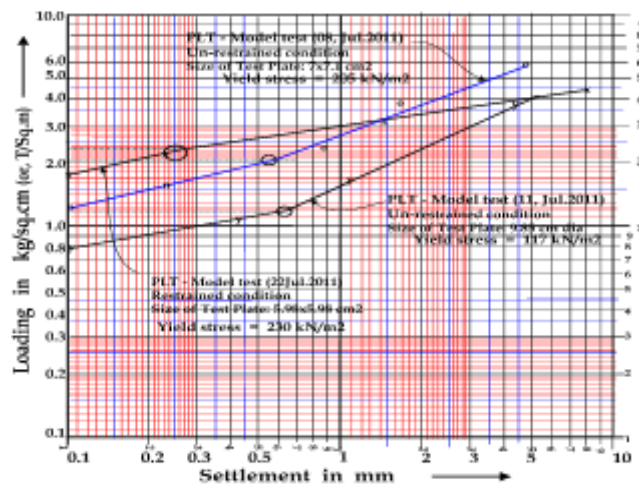**Figure 3(b): Load Settlement Curves Releated from PLT Model Tests No 1,2 & 3 on Untreated Subsoil of Type-I Soil given in Table-1 (in Log-Log Scale)**
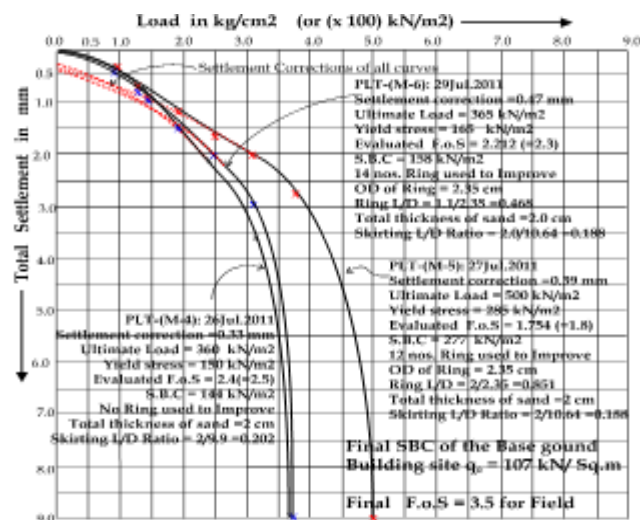

Figure 4(a): Load Settlement Curves Revealed from PLT Model Tests No 4, 5 & 6 on Treated Subsoil of Type-I Soil given in Table-1 (in Linear Scale)
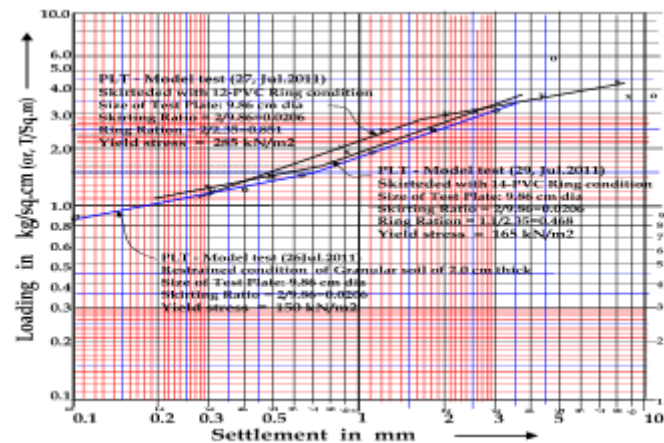
**Figure 4(b): Load Settlement Curves Revealed from PLT Model Tests No 4,5 & 6
on Treated Subsoil of Type-I Soil given in Table-1 (in Log-Log Scale)**

For comprehensive understanding of the present study, and to conclude the attitude of such model PLT with the achieved improved SBC, all form of final results inscribing the Type–I soil were find out and tabulated and are given in Table 5.

Table 5: Final Result Showing the Optimum CR and the Highest SBC Revealed from Model PLT with Soil Type-I

Basic data
Type of soil used: Laterite soil of gravelly silty sand (Table 1) compacted at closer to its OMC.
Size of loading plate used: Circular steel plate of 98.6 mm diameter & 7635 mm^2 area.
Outer skirt of steel ring : Length as OD =115 mm & Depth as used length of ring = 32 mm
Inner skirt of PVC ring forming HC-C : Length as OD =23.5 mm & Depth as used length of ring = 20 mm

Particulars about remoulded soil			Field conditions applied in PLT					Details of Model Plate Load Test			Improvement of treated SBC over untreated
Properties of soil used			Characteristics of hard inclusion			Layer-1 i.e. Foundation subsoil	Layer -2 i.e. Engineered soil	Load in Kg/cm^2	Total settlement in mm	SBC in t/Sq.m	
Parameters	Layer-1 forming base	Layer-2	IGSR	CR	Quantity						
Density in gm/cc	1.88	Nil	Nil	Nil	Nil	Field subsoil with gravel 60 – 12 mm	No 2nd layer	0.811	0.38	11.7	Remain same at surface level
								1.094	0.49		
Moisture content in %	14.95	Nil						1.658	0.80		
								2.364	1.45		
								3.704	4.75		
Density in gm/cc	1.88	2.0	0.174 for 20 mm thick granular soil for Layer-2	0.851	12 no. within outer Skirt	Field subsoil with gravel 60 – 12 mm	Field subsoil after passing 10 mm Sieve	0.822	0.39	36.0	308 % at surface level
								1.244	0.70		
								1.455	0.88		
								1.913	1.22		
Moisture content in %	14.95	14.95						2.512	1.61		
								3.111	2.08		
								3.710	2.75		
								5.083	9.23		

DISCUSSIONS

It is the challenges of the modern geotechnical engineers of the world civil engineering community that the weakest land having poorest SBC subsoil shall be made useful for engineering developments at site particularly for building and road projects. To achieve such kind of goal, soil improvement techniques are developing day by day with new processes. Hence, the overall consequences of the total efforts provided on this present study i.e. study on Bi-layer

foundation system (BL-FS) are also targeted at that objective. Moreover, to achieve a clear picture about how the improvement of SBC varies w.r.t. different types of subsoil under same field imposed condition were also studied simultaneously besides general engineering property aspect enhancement based on treated condition over untreated soil i.e. site occurrence condition. Therefore, a brief description of all about the whole systematic study on the considered subject is presented herein for benefit of the engineering community.

The procedure for achieving improved bearing capacity of 2nd layer subsoil for development of bi-layer foundation system so described and made available herein is a completely new process based on the new conception described earlier. In the main context of the paper, one type of soil i.e. Type-I soil is considered as base for describing the process of study and accordingly all possible forms of data were obtained and presented herein. However, the variation of improvement of SBC w.r.t different types of subsoil is not described earlier. Hence, for a comprehensive discussion the results of the same were prepared in tabular form and are given in Table 6.

Table 6: Final Result Revealed from Model PLT as Improved Geotechnical Properties of Treated Subsoil Type-I, II & III to be Used for 2nd Layer of BL-FS

Sl. no.	Type of subsoil used and their simple physical and geological description	Geotechnical properties revealed by Untreated subsoil				Geotechnical properties revealed by Treated subsoil under Skirting and HC-C condition				
		Density of subsoil 'γ' in (gm/cc)	Structural Formation	Ultimate Bearing Capacity (t/m^2)	Eva-luated FoS	Density of subsoil 'γ' in (gm/cc)	Structural Formation	Characteristic Ratio of hard inclusion		Ultimate Bearing Capacity (t/m^2)
								For Skirting "IGSR"	For HC-C "CR"	
1	Type-I:: Pale yellowish Brown colour Laterite soil of Lake deposit in recent period of geological origin.	1.88	In-situ Foundation soil of Layer-1 infinite depth	11.7	3.5	2.0	20 mm thick layer of granular mass as Layer -2	0.188	0.851	36.0
2	Type-II:: Reddish Brown Colour in wet condition Laterite soil of Lake deposit in recent period of geological origin.	1.70	In-situ Foundation soil of Layer-1 infinite depth	12.6	1.5	2.0	20 mm thick layer of granular mass as Layer -2	0.188	0.851	28.0
3	Type-III:: Light Blackish Gray Colour in wet condition Colluvial soil of Local Lake deposit in Tertiary period of geological origin.	1.94	In-situ Foundation soil of Layer-1 infinite depth	23.5	1.3	2.1	20 mm thick layer of granular mass as Layer -2	0.188	0.851	74.6

However, the study concludes that the optimum individual Characteristic Ratio (CR) of individual hard inclusions as a total SBC improving agents in combination of skirting (as Outer barrier) and HC-C (as Inner soil forming cell) are 0.188 (IGSR) and 0.851(CR) respectively as shows in Table 3, 4 and Table 5.

It is found from the Table 5 that types of soil has great contributing and controlling role in improving characteristics actions over their geotechnical properties.

CONCLUSIONS

Present study reveals the following conclusions:

- Achieving improved bearing capacity of weak subsoil is the principal geotechnical parameter for development of BL-FS.

- For BL-FS, recommendation of improved SBC particularly for 2nd layer of foundation subsoil comprising the surface foundation, treated with hard inclusions can possibly be made out through the laboratory model PLT only (Figure 2.a).

- The highest value of improved SBC i.e. about 3 times of untreated SBC (Table 5) for any type of weak subsoil may be generated by engineered granular soil mass treated with the optimum CR of HC-C elements as hard inclusions combined with optimum IGSR of outer skirt condition only.

- The optimum individual Characteristic Ratio (CR) of individual hard inclusions used as HC-C element is found at 0.851 and the same for skirting as improved granular soil ratio (IGSR) is 0.188 as shows in Table 2, 3 and Table 4.

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